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# THE USEFULNESS OF MATHEMATICS TO ENGINEERS

By PROF. P. W. OTT, *Department of Mechanics*

 HE intermediate position of the engineer between the field of pure science and the work of the every-day world has often been set forth. His special work is to dig into the mass of knowledge which has been slowly and laboriously accumulated by mankind and, by selecting and ingeniously combining the necessary facts, to evolve plans whereon he can build machines or structures for the benefit of himself and his fellows.

This task may be anything from the taking of a few simple facts regarding springs and statics and evolving a mouse trap to the building of a giant battleship, or that magnificent machine at Panama which will lift the battleship over the back of the continent.

Before the engineer may hope for success in such a work, he must be in possession of at least some knowledge of the facts of science and have the ability to compute or estimate the quantitative relations involved in the solution of his problem. These involve not only the elements necessary to make the machine or structure fulfil its purpose, but also the cost, the time necessary for construction, and the economic value of the work.

In short, the engineer must be something of a scientist and mathematician, endowed with foresight, ingenuity and common sense, as well as honesty, courage and vision. This sounds like a pretty large order; but in this enlightened country, it would be difficult to find, outside a home for imbeciles, any one entirely lacking in all of these prerequisites. Consequently, any one may engage in engineering work—say, make the mouse-trap, or build a fence around his chicken-run—and may do so successfully and safely, provided he has sufficient common sense to recognize his limitations.

It is not remarkable that engineers, as a co-incidental part of their work, have added materially to the store of knowledge of science and mathematics, for they have not always found the materials and tools ready-made for their hands. In the same way and perhaps to a greater extent, scientists and mathematicians have added to related fields, as well as to their own. Indeed it is difficult to draw a distinct line between any two of these fields. However, the subject of the interrelation and mutual contributions of these sciences and arts is not the theme of this paper, even though it might prove more instructive and would certainly be more entertaining than a de-

scription of the various branches of mathematics and their usefulness to engineers.

If a student can recall the order in which the various "branches" of mathematics were presented to him in his formal education, he has them, almost, arranged in their order of usefulness to him. Perhaps it is fortunate that the student is more gullible at first than later, since it leads to a better mastery of the most fundamental part of mathematics. In his later years of study he becomes skeptical (perhaps rightly) of the utility of certain parts of the subject and tries to acquire that nice degree of mastery which will "get by" the final examination and still not leave his mind cluttered up with useless nonsense!

It is true that the practice of the vast majority of engineers calls for little more than a mastery of arithmetic and geometry and a passing knowledge of trigonometry and algebra. Many of them, in forgetting their higher mathematics, forget also how greatly indebted to it they are for their understanding of science and even for the very origin of the formulas on which they so brilliantly exhibit their skill in arithmetic.

As for arithmetic, the student must be thoroughly grounded. He must be rapid and accurate, and, above all, must acquire the habit of orderly and systematic computation, so that his operations and results can be easily read and checked. There is usually no

course in simple arithmetic given in college, in spite of the fact that the primary and secondary schools do not do their full duty. The student is left to his own devices. He must begin early and keep at it. Addition, subtraction, multiplication, division, involution and evolution, fractions, ratios and decimals are of every-day usefulness to the student and to the engineer. Learn the short cuts and learn to check. For complete multiplication and division the 9 check-figure method gives an almost sure check. Most engineering calculations involve data of a known degree of accuracy, indicated not by the number of places beyond the decimal point, but by the number of significant figures. Multiplications and divisions with such quantities, when not done by logarithms, should be done by the "bob-tailed" method given by the late Professor Bohannon in his "Plane Trigonometry."

In the long hours of math class you may have wondered what good it would all be to you, we'll admit that we have often done so. There is a general lack of interest in mathematics among lower classmen that is to be deplored. They probably fail to realize that mathematics is a very convenient tool and not something that must be taken because it is listed among the required subjects. As the engineering student has more experience he realizes that it is very much easier to solve a problem by means of mathematics than by the sometimes more apparent cut and try method.

We feel that there is need for men taking mathematics to consider the application of the theoretical training as they receive it, as we think that in this respect our mathematic courses could be improved. The training in rigorous thinking that is developed by the conscientious study of mathematics is absolutely necessary if the engineer expects to follow engineering work. Even sales work is about a half engineering, the salesman being about as much of a consulting engineer as he is a salesman. Therefore let the engineer regard his mathematics as a friend who is willing to help him and not as a burden that must be carried to satisfy convention.  
—Editor.

(Continued on Page 32)

## THE USEFULNESS OF MATHEMATICS

(Continued from Page 13)

Let us illustrate this method by multiplying 487.62 by 64.753:

$$\begin{array}{r}
 \text{---} \\
 487.62 \\
 64.753 \\
 \hline
 292572 \\
 19505 \\
 3413 \\
 244 \\
 14 \\
 \hline
 31574.8 \text{ or } 31575
 \end{array}$$

Instead of beginning with the 3, as is usual, begin by multiplying by the 6, bringing down the result, 292572, below the line and draw a line to cancel the last figure of the multiplicand. Then multiply by the second figure, 4, of the multiplier, starting by multiplying the figure just canceled.  $4 \times 2 = 8$ ; this is nearer ten than zero, so carry one.  $4 \times 6 = 24 + 1$  (the carried figure) = 25. Place the five below the last figure, 2, of the 292572, carry 2, and proceed, as usual, to multiply by 4 the rest of the multiplicand, canceling the next to last figure, 6, of the multiplicand, when through with the operation. Continue in this manner until all figures of the multiplier have been used. Then add, pointing off the original number of decimal places, in this case 5, less the number of canceled figures, 4. The result is just as accurate as a complete multiplication would have been and about a third of the work has been saved.

The only difficulty here is changing the habit of going from right to left on the multiplier to the reverse. In division, even this trouble is saved, the only change in habit being to cancel a figure in the divisor whenever tempted to add a zero to the dividend. Multiply each new figure of the quotient by the last canceled figure of the divisor to get the number to carry.

$$\begin{array}{r}
 487.62 \\
 \hline
 64.753 \overline{) 31574.8} \\
 \underline{259012} \phantom{0} \\
 56736 \\
 \underline{51802} \phantom{0} \\
 4934 \\
 \underline{4534} \phantom{0} \\
 400 \\
 \underline{388} \phantom{0} \\
 12 \\
 \underline{13} \\
 \hline
 \phantom{000000}
 \end{array}$$

Note that the first figure, 4, of the quotient is placed directly above the first figure, 2, obtained when the divisor was multiplied by the 4, and that the decimal point of the quotient is put three places (the number of places in the divisor) to the right of the decimal point in the dividend. Get from the library a copy of Bohannon's "Plane Trigonometry" and study carefully the chapter entitled, "Calculation Vices and Devices." Also study the first chapter, which is on *Logarithms*.

Geometry is a universal preparatory requirement for technical courses. Many of the propositions are of every-day usefulness. The rest, and the logical system of reasoning involved, are necessary for the development of the geometric sense which enables the student or the engineer to translate drawings into ideas and vice versa. It is the foundation for Descriptive Geometry, probably the most important of the fundamental technical courses, and of all work involving graphical methods—a large field. No student should be satisfied with a half-baked knowledge of "Descrip." However, once having gained a real mastery of the subject, he should not be discouraged if he cannot readily recall the solution of particular problems. This ability seems to be retained only by constant practice. The real function of the study is as a brain-stretcher. The ability to "see things in space" never departs.

Trigonometry, next to arithmetic, is the most useful mathematical tool for the engineer. The computing of projections and the solution of triangles must be reduced to permanent mental impressions. Miscellaneous juggling of trigonometric equations may be of less value, but such equations arise with remarkable frequency in engineering computations. To handle them, the student must recognize the fundamental trigonometric identities on sight. If he knows the identities and the rules for solution of triangles "off hand," he can afford to depend on reference to books for the rest.

The most important thing in Algebra is doubtless logarithms, if this branch is to be judged from its practical utility. This is merely a high-powered motor for arithmetic. It speeds up computation, and removes a vast amount of labor, as well as possibility for errors. Students and engineers alike seem to have a tendency to neglect this fine tool, unless it can be said that they use it when they use the slide rule. Perhaps one reason for this neglect is the fear that the trouble of looking up values and interpolating in tables will not be repaid by the saving of labor in computing. There is no excuse for this fear, in the face of modern graphical log tables, which remove all the labor of interpolating as well as most of the chance of reading the wrong value. As for the rest of Algebra, the student must be able to solve simultaneous linear equations and quadratics without the necessity of referring to a text. In such solutions, make an orderly arrangement and a numbering of the equations a habit. Indicate what each operation is by such simple statements as: "Transpose (3)," "Collect coefficients of  $x$  in (4)," "Divide (5) by the coefficient of  $x$ ," etc.

It should be said here that it is useless to be able to juggle equations unless you can originate them, that is, to express relations in mathematical language. Perhaps the ordinary courses in mathematics, from algebra and trigonometry onward, put too little emphasis on this side of the subject. Lack of ability to do this is certainly the most outstanding mathematical deficiency of upper-classmen in college.

Equations involving higher powers of the variables, and equations transcendental on one side and algebraic on the other occasionally arise in practical work. If the computer knows what he

(Continued on Page 36)

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## THE USEFULNESS OF MATHEMATICS

(Continued from Page 32)

is doing he can make a good guess as to what values will nearly satisfy such equations, and then the method of "cut and try" will lead to a solution with surprisingly little labor. In a cubic, one root by cut and try usually leaves two easily found by the solution of a quadratic.

Let the student be not discouraged if he finds, a year or so after taking, that he seems to have forgotten some of his algebra, and let him not regret his lost labor in learning it. Skill in juggling equations is invaluable and comes only from practice. It is quite possible for him to be confronted in some actual computation with the problem of solving several dozen simultaneous equations in an equal number of unknowns. This will cause him to compare his formal course in algebra to an introduction to a wall-flower with whom he afterwards has to dance. The strict necessity of conforming to her style makes the analogy quite pat.

"Check and be checked," is the most important phrase applicable to engineering computations. For algebraic work no method beats substituting back in the original equations. Computers are usually paid on a basis of time, rather than the job. This is fortunate.

A student taking the usual course in "math" prescribed for engineers will take Analytical Geometry. This subject is based almost wholly on Des Carte's invention of a method of representing equations of one, two, and three variables as curves and surfaces in space. Most people are endowed with what may be called a "geometric mind," and this endowment is deliberately cultivated in an engineering curriculum. Consequently, the ordinary student gets from analytical geometry a new and distinctly gratifying understanding of equations and their meaning and relations, provided, of course, the study "takes" and is not merely something which must be taken. As an engineering tool it is rather limited, but it starts the student thinking in "curves," and thinking in "curves" is so fundamental in the analysis of the vast majority of engineering problems that no labor is ever lost which tends to develop the talent. After taking this course, "curve thinking" soon becomes a fixed habit. Ask any engineering junior what he means by yield point of steel, and the chances are he will begin, "It is the point on the curve . . . ." From a strict analytical standpoint this is delightfully hazy and wholly incorrect, but he knows what he is talking about and his hearer, with a little esoteric knowledge, knows too. He saves a lot of thinking time, and some words; and from a standpoint of symbolism, he is quite right.

There is a fairly large number of practical engineering problems to which Analytical Geometry is directly applicable—problems in which space relations are solved analytically, but even without these the subject well merits all the time spent on it in college, and probably more.

Calculus has been made much easier by the concept of curves to represent equations. If the student, on beginning the study of calculus, has a substantial foundation in algebra and analytical geometry, he should have no difficulty with the calculus, and will get a real "kick" out of the new ideas involved. Otherwise, calculus is very apt

to prove a horrible nightmare for him, in which he dreams he is forced to learn the meaning of the meaningless.

As a matter of fact, the engineer who needs calculus is rare, and the one who can use it with facility, still rarer. It is a tool of considerable potential value, which is usually neglected and allowed to rust. Of course the engineer is indebted to it for many of his fundamental formulas. Perhaps it would be wise for the student to resolve to free his mind from the burden of remembering such formulas, and make it a practice to run through the development whenever he needs one. For many of them, the task calls for but a few minutes of time, and the plan would keep the calculus polished and ready for work.

The tool is particularly useful to the engineer in the solution of maximum and minimum problems, a use which involves the easier part of the calculus.

If the subject had no use whatsoever in engineering practice, its study would be necessary for an understanding of the student's work in the last two years in college. It is particularly important that the student really understand the formulas derived by the calculus, even though he can use them practically with nothing more than arithmetic as an aid.

From a poll of engineering teachers made by the Society for the Promotion of Engineering Education, it appears that over 95% of those interested enough to answer the questionnaire believed the above branches of mathematics absolutely fundamental and essential for *all* kinds of engineering. This is a higher rating than was given to any strictly engineering subject. Mechanical drawing got 93.5% and mechanics of materials, 89%. Descriptive geometry got only 70%, which is probably less than it merits on its head-stretching value.

If the student does not have a very thorough knowledge of these branches, he should not attempt anything higher, but should devote his time and energy to a thorough review, working plenty of problems, especially those involving the putting of ideas into mathematical language. If he has a fair knowledge retained from his class work, he will probably profit by using, for his review, different texts from those used in his formal courses.

If the student has a good grasp of the fundamentals he may, with profit, pursue some advanced courses. First of these to suggest itself is Differential Equations (which received a vote of 29% in the polls referred to above). This subject is a superstructure on calculus, having for its main purpose the finding of relations among variables to satisfy any given conditions regarding the variables and their derivations. Expressed in the language of "curves," it attempts to find the curves which satisfies, at every point, any desired relation among the ordinate, abscissa, slope, rate of change of slope, etc., and then to pick from all such curves the particular one which passes through given points, is tangent to given lines or meets other required conditions. Needless to say, it is easy to fix up a jumble of relations which can be solved only in theory, but a large number of useful relations *can* be worked out. This subject probably has a greater prac-

(Continued on Page 38)

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(Continued from Page 36)

tical utility to engineers than does calculus. It is an extremely essential tool for researchers and experimenters, and all those engaged in engineering requiring much analytical thinking. In modern electricity it is almost indispensable.

With the completion of Differential Equations, the law of diminishing returns begins to be rather conspicuous in the picture. There are, however, a few more mathematical subjects which can be useful to the engineer, if he stands in a position in his profession which places him near the scientist.

These are, in the order of their probable value:

(1). Least Squares and Theory of Probability. This subject cannot be considered a distinct branch of mathematics, but is often given as a college course. It finds its practical application in the adjustment of observations and determination of most probable values and of the probable error of any result of observations. Throughout his technical course, the student is brought into some contact with the theory and an entire lack of knowledge of it is a distinct deficiency in his training.

(2). Vector Analysis. This is a distinct branch invented (or, more properly, wrested from the arms of Quaternians) to enable us to handle problems in all kinds of quantities involving magnitude and direction. The student is introduced to it early in his course and makes considerable use of it in an elementary way, by the cumbersome method of resolving on co-ordinate planes to reduce the analysis to Algebra. A formal course should clear up his haziness regarding this type of quantities, as well as give him a distinctly new vision and understanding of the ordinary geometrical precepts. Also, this subject has the advantage of being easily grasped, due to its geometric nature. Vector Calculus is an extension of the subject of great interest and of much value as a mental stimulant.

(3). Fourier's Series. This subject, usually taught in connection with problems in harmonics, develops a method of expressing as one continuous, integrable, function any "curve" made up of a number of ordinary algebraic functions. For example, a curve made up of a number of straight lines of different slopes, arcs of circles, ellipses, parabola, and what not, can be expressed in a single equation. The application comes in putting in the limiting conditions for solutions of differential equations, particularly in problems of potential, flow of heat, electricity, stream-line flow, harmonic periods, etc. It is practically worthless to one who has not a good grasp of Differential Equations, but is a tool of inestimable value in the hands of the skilled mathematician.

(4). Calculus of Variations. Perhaps this should be omitted because it is probably not of practical utility to one engineer in a thousand (and also because the writer is profoundly ignorant on this subject himself). The subject develops a method of finding functions to fit given conditions (and particularly maximum and minimum functions) without knowing any relations among the variables or their derivatives, as is the case with differential equations. The method seems, originally, to have been invented to solve

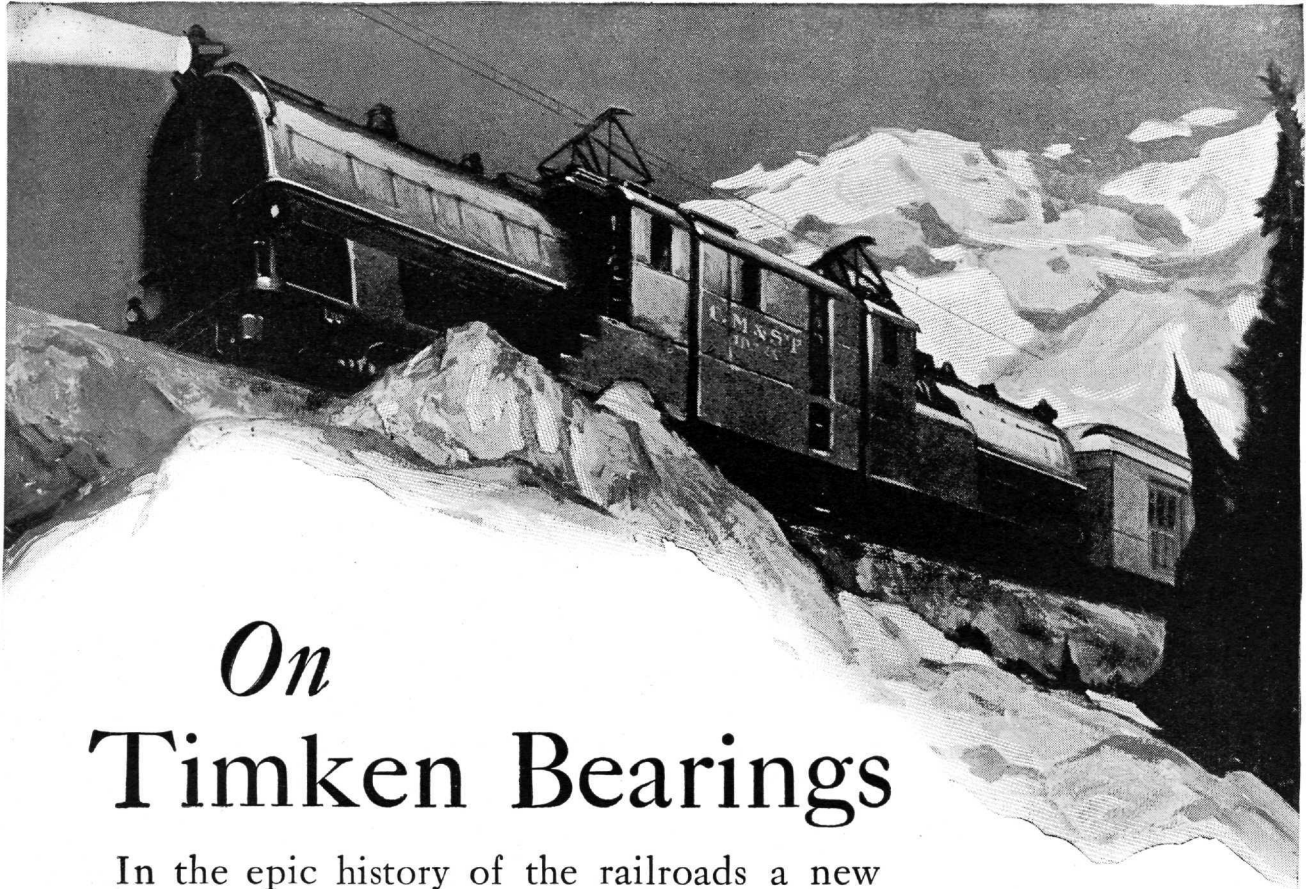
the problem of the path of quickest descent. Text books usually begin with an extremely abstruse proof, involving no assumptions whatever, that a straight line is the shortest distance between two points. As an application to mechanics, the writer has succeeded, by this method, in proving that radii remain straight in a round shaft under torsion, and that vertical lines on a beam remain straight when the beam is bent, these being our fundamental assumptions for computing stresses in beams and shafts.

Aside from any possible practical utility, the subject should have great value as a "head-stretcher"; but a head-stretcher is somewhat like a hat-stretcher, which cannot be made to function unless it can be gotten into the hat.

It may be said of all the foregoing courses that if studied aside from their applications, much of their value will be lost. The student should intermingle with them courses in such subjects as thermodynamics, electricity, physics, mechanics, mathematical physics, and physical chemistry. It is only by continual practice on problems already solved that the mathematical method becomes a habit and may be readily applied to new problems. The student should remember that mathematics is a pyramidal structure, and each new part of the superstructure must be laid on the firmest possible foundation. If he is merely building a house of cards, a collapse is nothing more than ludicrous, but if he is making practical use of his creation, a failure may be fatal. The whole process of learning mathematics requires practice and rigid application to problems. The student should hold himself to the task of solving every problem in his text, and some more of his own devising, proving his answers, when no answers are given. No text ever had too many problems. No student who has anything beyond a diploma in view should let "credit" tempt him to take a course for which he is not prepared.

Blind faith in mathematics will not do, at least for the engineer. He must understand its true nature—that it is only a method of reasoning. He must proceed with mathematics in one hand and with common sense in the other, keeping ever a lookout for the reasonableness of his results. Nothing reasonable ever came out of a computation which was not originally put into it in the fundamental assumptions. No calculation can give a result more accurate than the data on which it is based. Mathematical concepts are perfect, the physical conditions to which the engineer applies them never are. All results are in error and it behooves the engineer to know (within limits) how much. His result may be accurate to one-tenth of one part in a million, as in his analysis of the impurities in drinking water, or plus or minus 50%, as in his calculations of the stresses in a structure built to withstand the vagaries of the storms. All formulas are empirical, in that the "rational" ones are derived from empirical ones. None, with the possible exception of Newton's laws, exactly fit the things to which they are applied. When the fiery steed of mathematics is hitched to the block-wheeled cart of utility, every strap of the harness must be properly applied and still the cart will go more slowly and roughly than goes the steed alone.





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